EXHIBIT 9

NHTSA'S RECENT COMPATIBILITY TEST PROGRAM

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ABSTRACT

NHTSA has developed and conducted a vehicle-to-vehicle crash test program to evaluate the statistical correlation between vehicle performance measures and the probability of driver fatality in a crash partner vehicle. The test program uncovered some concerns regarding NHTSA's rigid barrier data collection and review methods. The vehicle-to-vehicle tests did not provide clear insight into the mechanism behind the fleet correlation, but did emphasize the complexity of vehicle compatibility and the changing safety priorities related to improved occupant restraints.

INTRODUCTION

In September 2002, the National Highway Traffic Safety Administration (NHTSA) formed an Integrated Project Team (IPT) to conduct an in-depth review of vehicle compatibility [1]. This team was chartered to identify innovative solutions and recommend effective strategies to improve vehicle compatibility. One of the strategies developed by this team was to initiate a test matrix to investigate opportunities for vehicle crash partner protection. This paper documents the development, analysis, and results from this test program.

In recent years, NHTSA has conducted several crash test and statistical studies to evaluate vehicle compatibility. These studies attempted to correlate the results from staged crash testing with the fatality and injury consequences observed from the accident databases. The IPT recommended a vehicle-to-vehicle test program to explore the results published in the report, "Vehicle Weight, Fatality Risk, and Crash Compatibility [2]."

In this report, Kahane evaluated the fatality risk to the driver of a passenger car when struck by another passenger car or an LTV. The fatality risk for vehicle models were compared against compatibility measures derived from U.S. New Car Assessment Program (NCAP) testing. The average height of force (AHOF) and initial stiffness were evaluated as predictors of real world crash outcomes [3].

Kahane found that the difference in the AHOF between the struck and the striking vehicles had a statistically significant negative effect on the fatality risk to a car driver struck on the left side. A passenger car driver struck by a vehicle with a relatively higher AHOF would have a greater risk of fatality. No correlation was found by Kahane for front-to-front crashes, but subsequent research indicated that a correlation exists only for belted drivers struck front-to-front by a vehicle with a higher relative AHOF [4].

In addition to the geometric aspects of AHOF, Kahane evaluated the energy absorption or front-end stiffness of the striking vehicle. NHTSA had previously developed a methodology to compute a front-end stiffness measure from a linear fit to the force-deflection profile in NCAP testing [3]. Kahane found that the stiffness of an LTV had a statistically significant positive effect on the fatality risk for a passenger car driver struck in the front. The study also found that the stiffness of a striking car in a left side impact had a statistically significant positive effect on the fatality risk of the struck car's driver.

In order to evaluate these statistical results, it was desired to implement a vehicle-to-vehicle test program to evaluate how the striking vehicle characteristics affect the safety performance [5]. It was decided to use three classes of bullet vehicles: minvans, SUVs, and pickups. Two vehicles from each category were selected to have similar size and weight, but with different compatibility measures. These six bullet vehicles were tested in a series of vehicle-to-vehicle crashes against a single target vehicle. The occupant injury measures in the target vehicle were used to assess the compatibility of the striking vehicle.

TEST PROGRAM

It was desired to select a test program that closely resembled the fleet crash environment, but that also drew from industry standard practices, so the results could be readily interpreted. Data from the National Automotive Sampling System-Crashworthiness Data System (NASS-CDS) from 1998 to 2001 was evaluated [5]. NHTSA evaluated the frequency and distribution of impact angles, overlaps, and speeds. Comparing the crash data with industry practices, three tests series (full frontal colinear, 50 percent offset, FMVSS No. 214 configuration side impact tests) were selected. The full frontal and frontal offset tests were chosen to be conducted using the methodology described by Ford [6]. For these tests, the target vehicle is stationary and the bullet vehicle is towed at the appropriate speed to provide a 56 kph change in velocity for the target vehicle in the full frontal test. The same bullet vehicle speed is also used for the offset test. The colinear offset test is aligned for the bullet vehicle to engage 50 percent of the target vehicle. For the FMVSS No. 214 configuration tests, rear wheel assemblies are used to allow the bullet vehicle to be towed at a crabbed approach angle. There was discussion on whether to use the lateral NCAP impact speeds but in the end, the 214 speed was selected to allow comparison with previous NHTSA tests [7]. In total, 18 vehicle-to-vehicle tests were conducted. Each of the seven vehicles was also crashed into a 125 mm resolution load cell barrier to verify the AHOF and initial stiffness measures.

The bullet vehicles were selected as three pairs of similar vehicles, minivans, SUVs and full size pickups. The vehicle pairs were selected to have similar weight to minimize any mass effects that were not controlled by the test conditions. The vehicle pairs were also selected to maximize the differences between the AHOF and initial stiffness measures. For the SUV pair, the Chevrolet Trailblazer was selected as the higher, stiffer vehicle and was paired with the Ford Explorer. The Dodge Ram was selected as the higher, stiffer pickup and paired with the Toyota Tundra. For the minivan category, there was no ideal pair of recently tested minivans. The Dodge Caravan was selected as the higher but softer minivan and paired with the Chevrolet Venture. The target vehicle was selected on the basis of good NCAP and the Insurance Institute for Highway Safety (IIHS) offset performance. It was also decided to use a target vehicle with side curtain air bags. These safety countermeasures are expected to be more representative of future vehicles in the U.S. fleet.

After a review of recent NCAP tested vehicles, the 2004 Honda Accord was selected. When completed, the test matrix should provide data for evaluation of the vehicle crash partner protection initiatives that were identified in NHTSA's IPT report on vehicle compatibility.

HIGH RESOLUTION BARRIER TESTING

NHTSA has recently developed a new 125 mm high resolution load cell barrier for use in evaluating vehicle crash compatibility. For over twenty years, NHTSA has conducted frontal NCAP 56 kph rigid barrier testing. These tests measured the crash forces using a 4 by 9 load cell array. The load cell data from these frontal NCAP tests have been analyzed to evaluate performance measures that may relate to vehicle compatibility. The matrix of force measurements has been used to evaluate the height and distribution of crash forces for over 500 vehicle crash tests conducted under the NCAP program. It is desired to evaluate the crash results for the high-resolution barrier and compare the results against the lower resolution load cell barrier. These tests were intended to verify the previous data and to evaluate the increased resolution and geometric differences between the load cell barrier designs.

There are a wide variety of load cell barriers in use today. The barriers differ in size shape and in the layout of the load cell sensors. NHTSA, in conjunction with the International Harmonized Research Agenda (IHRA) Compatibility Working Group, has developed a standard load cell barrier configuration that would encourage broad comparison of load cell barrier results. The IHRA Compatibility Working Group has standardized on the use of 125 by 125 mm load cells. NHTSA has developed an 8 by 16 array of single axis load cells. Each load cell is rated for measuring up to 300 kN of compression. The test series was conducted with the barrier mounted 125 mm above the ground to be consistent with the Japanese Ministry of Land, Infrastructure, and Transport (JMLIT) NCAP program. Subsequently, the IHRA compatibility group recommended a standard height of 80 mm ground clearance. The 125 mm ground clearance used for this test series is higher than the older NHTSA load cell barriers, 67 mm. However, even this additional mounting height was not sufficient to engage the front structure of all seven test vehicles. Pre test alignments shown in Figure 1, demonstrated the potential of vehicle

contact above the load cell array. The load cell barrier was augmented to create a partial ninth row using six spare load cells, as shown in Figures 1 and 2.

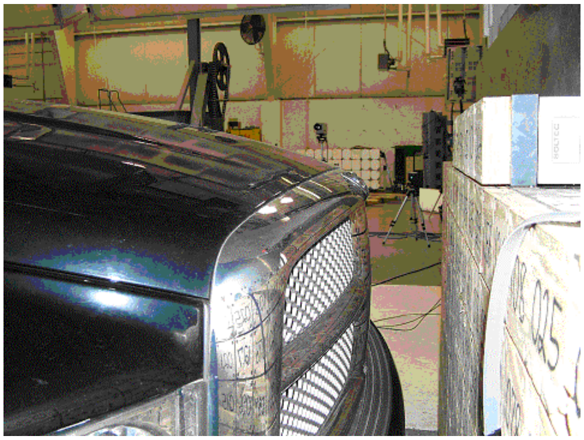

Figure 1. Pre test allignment for the Toyota Tundra

Figure 2. Load cell barrier augmented with partial ninth row

The vehicles tested in this test series are shown in Table 1. Only the Caravan was tested without the partial 9th row of load cells. The test numbers refer to the NHTSA Crash test database and can be used to obtain the complete test results [8].

Table 1. Rigid Barrier Test Vehicles

Test	Year	Make	Model	Speed (kph)	Weight (kg)
5062	2004	HONDA	ACCORD	56.6	1624
5087	2001	CHEVROLET	VENTURE	56.3	1975
4990	1996	DODGE	CARAVAN	56.3	1976
5034	2002	FORD	EXPLORER	56.3	2263
5036	2002	CHEVROLET	TRAILBLAZER	56.7	2339
5073	2002	TOYOTA	TUNDRA	56.3	2422
5061	2002	DODGE	RAM	56.4	2582

The vehicles in Table 1 were based on previous results from NCAP frontal barrier tests. The initial NCAP tests are shown in Table 2 below and will be used to compare results against the high-resolution data. The NCAP test for the Honda Accord was run at MGA using their load cell barrier, which has a 2 by 3 matrix of force measurements. The MGA load cell data is only used to compare total force measurements due to the limited spatial resolution. The NCAP tests for the Chevrolet Venture and Ford Explorer were conducted at Karco, Inc. At the time of these tests, the fourth row of the Karco load cell barrier was not working. These two tests only include measurements from the lowest 3 rows of the barrier. Additionally, one of the columns was inoperable for a total of 24 load cell measurements. The missing column of force measurement did not appear to be significant, but it appears that the missing 4th row of load cell data may have had significant consequences, particularly for the Ford Explorer test.

Table 2. NCAP frontal barrier tests

Test	Year	Make	Model	Speed (kph)	Weight (kg)	Load Cells
4485	2003	Honda	Accord	55.8	1571	6
3676	2001	Chevrolet	Venture	55.8	1971	24
2997	1999	Dodge	Grand Caravan	56.3	2011	36
3730	2002	Ford	Explorer	55.3	2323	24
4244	2002	Chevrolet	Trailblazer	56.49	2348	36
3915	2002	Toyota	Tundra	56.2	2401	36
4240	2002	Dodge	Ram1500	56.5	2518	36

Figure 3 shows an overlay of the high-resolution and NCAP barriers. The NCAP barrier is slightly wider and is mounted lower, 67 vs. 125 mm. The increased height of the high-resolution barrier may have been important for the taller vehicles. The NCAP barriers provide a reaction surface above the load cell array, flush with the load cell face. The narrower width of the high-resolution barrier appeared to be adequate for all vehicles in this initial test series.

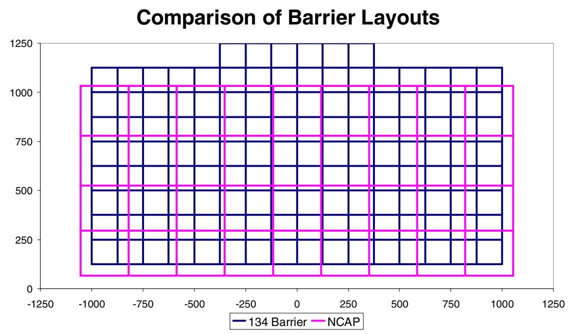

Figure 3. Comparison of NCAP and HR barriers

Total Force

In general, the total force time history measurements compare well between the NCAP and high-resolution (HR) test series. For all tests, the total force from each pair of tests displays a similar shape, duration and amplitude. The larger LTVs, particularly the Explorer and Ram, show more significant deviations between the two tests series. The Explorer HR test has a higher initial peak and the force drops off quicker after 50 ms. The Dodge Ram HR test has higher force than the NCAP test throughout most of the test, particularly between 60 and 80 ms. The front-end profiles for the seven vehicles are shown in Figure 4 below. The heavy line from 125 to 1125 mm on the Y-axis indicates the height of the HR load cell barrier. The three tallest vehicles in the test series all measured a peak force near 50 kN on the 8th row of the HR barrier. The Toyota Tundra measured a peak force greater than 20 kN on the partial 9th row of the HR barrier. The comparatively high peak force measured in the Tundra barrier tests may present an increased likelihood of intrusion for crash partner vehicles.

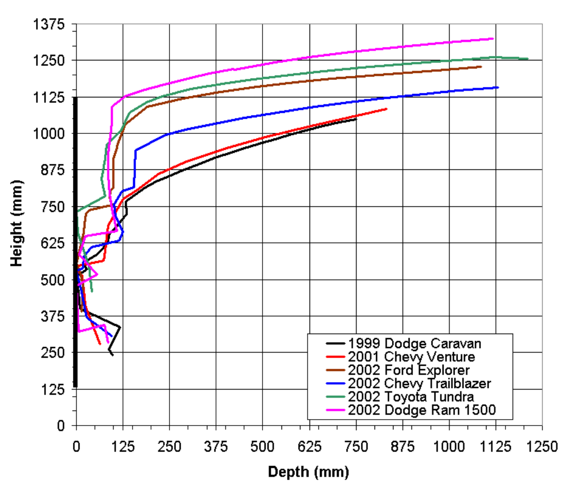

Figure 4. Vehicle Profiles

The correlation factor was computed to provide a numerical estimation for the similarity between the total force measurements. The correlation factor is an estimate of the likelihood that two signals could be equivalent with a linear transform. For two signals F(t) and G(t), the correlation factor is computed according to Equation 1 [9]. The correlation factor was computed from time 0 until one of the test vehicles reached zero velocity.

$$CF = \frac{\sum_{i=1}^{n} F_i G_i}{\sqrt{\sum_{i=1}^{n} F_i^2}\sqrt{\sum_{i=1}^{n} G_i^2}} = \frac{\sum_{i=1}^{n}\left(F_i - \overline{F}\right)\left(G_i - \overline{G}\right)}{\sqrt{\sum_{i=1}^{n}\left(F_i - \overline{F}\right)^2 \sum_{i=1}^{n}\left(G_i - \overline{G}\right)^2}} \quad (1)$$

The correlation factors between the HR and NCAP total force measurements range from 98.6 to 99.8. This supports the general observation that the shape, amplitude and duration are similar for both test programs.

One of the principle quality checks for the historical load cell data was to evaluate the total force data against vehicle accelerometer measurements. Assuming the vehicle's mass does not change during the crash, the integral of the total force divided by the vehicle mass should approximate the velocity time histories measured by the vehicle accelerometers. This qualitative evaluation was used extensively for reviewing the historical NCAP test data [10], and was the basis for accepting the data from barrier tests with only 3 rows of load cell measurements. Generally tests with erroneous load cell or accelerometer data can be readily identified by the divergence of the accelerometer and load cell velocity estimates. Most of the NCAP and HR tests show good comparison between the velocity data. The Ford Explorer NCAP test shown in Figure 5 mildly under-predicts the velocity change, indicating that most of the force was measured through the lower 3 rows of the NCAP barrier.

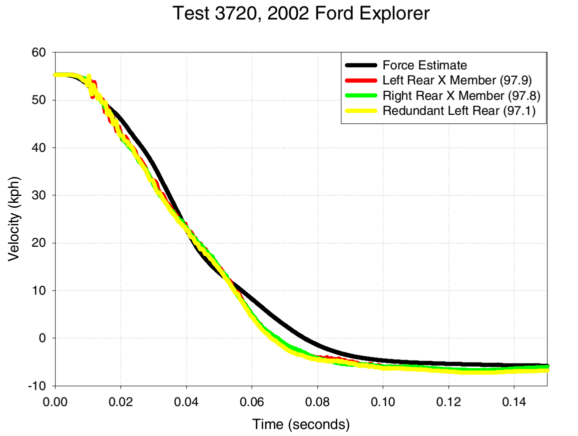

Figure 5. Velocity check for Ford Explorer NCAP test

The correlation factor was also used to compare the accelerometer and load cell derived velocity signals. The correlation factor was computed between time zero and the time when the force estimated velocity crossed zero. Historical review of NCAP test data have shown that the correlation factor is generally > 0.98. Additionally, a correlation factor below 0.95 often indicated a problem with the test data. Conversely, a correlation factor greater than 0.95 did not provide an additional estimate of data accuracy. Figure 6 below shows the correlation coefficients for the velocity estimates. The NCAP and HR barrier tests are generally in the same range for the correlation coefficiant. Of the high resolution tests, only the Ford Explorer had a correlation coefficient below 0.99.

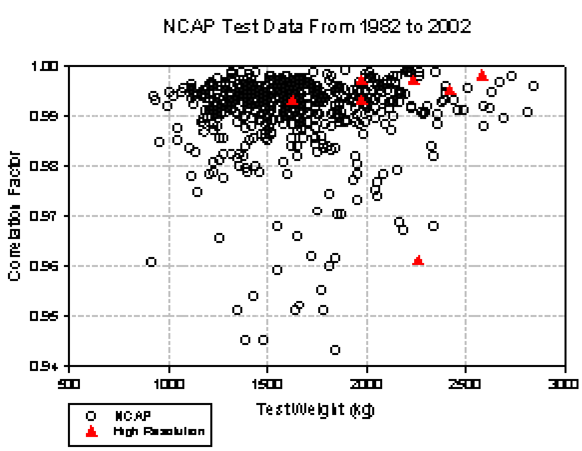

Figure 6. Velocity correlation factors for NCAP and high resolution barrier tests

Evaluation of the total force measured in the NCAP and high-resolution test programs raised some concerns regarding the repeatability of the total force measurements. The increased height of the high-resolution barrier and the loads measured in this region seem to indicate that previous NCAP testing did not measure all of the crash forces for the large LTVs.

Height of Force

The AHOF is a measure of the characteristic height at which the vehicle loaded the barrier during the test. At each time step, the Height of Force (HOF) is computed as shown in Equation 2 below, where n represents the number of load cells in the barrier. The HOF(t) represents the height which the total force should act to produce an equivalent moment about the ground.

$$HOF(t) = \frac{\sum_{1}^{n} Fi \times Hi}{\sum_{1}^{n} Fi} \qquad (2)$$

The HOF(t) is then averaged, using the total force(t) as a weighting function. The weighting function biases the AHOF to the time(s) when the force is highest. The resulting AHOF can be considered the characteristic height at which the force was transferred to the barrier during the crash. The AHOF is computed using Equation 3.

$$AHOF = \frac{\sum_{0}^{t} HOF(t) \times F(t)}{\sum_{0}^{t} F(t)} \qquad t = time\ step \qquad (3)$$

The HOF(t) and the AHOF can only be computed for times when the total force is not near zero. At the beginning or end of the crash, a low total force can lead to numerical instability in the computation. The AHOF for all of the tests was computed over the time duration where the total force exceeded 50 kN. The AHOF for the NCAP and HR tests are shown in Table 3 below. The AHOF is not shown for the Accord NCAP test, which was conducted using the 2-row load cell barrier at MGA Research.

Table 3. AHOF measurements

	NCAP AHOF	HR AHOF	Change (mm)
Honda Accord		414.5	
Chevrolet Venture	449.0	496.0	47.0
Dodge Caravan	534.0	553.0	19.0
Ford Explorer	495.5	593.4	97.9
Chevrolet Trailblazer	561.2	562.8	1.6
Toyota Tundra	516.9	575.6	58.7

Dodge Ram	570.1	587.7	17.6

The variation in AHOF between the NCAP and HR tests varied between 1.6 and 97.9 mm. The large discrepancy for the Explorer and Venture tests are likely due to missing fourth row of load cell data in the NCAP test. However, the Tundra test had complete NCAP data but had a 59 mm difference in the AHOF. This would lead to the conclusion that the relative size of the barriers and test vehicles leads to the higher AHOF's for the HR barrier. However, the Ram, Trailblazer and Carvan, demonstrated much lower AHOF differences. The vertical impact point was not measured for this test series, but was shown on subseqent test series to vary as much as 20 mm from the static pretest alignment. The AHOF repeatability is also limited by the approximately 250 mm load cell size for the NCAP tests. If the AHOF can only be expected to be accurate to within ¼ of the load cell size, then only the Explorer exceeds the accuracy expectations.

Figure 7 shows the HOF(t) for the Honda Accord as the green line. The AHOF is indicated by the dashed red line in Figure 7. The blue curve shows a running average for the HOF(t) and visually indicates how the AHOF converges to its final value. There is a large difference in the HOF(t) for the early and late phases of the crash. This behavior is typical for passenger vehicles where the engine generally impacts the barrier late in the crash.

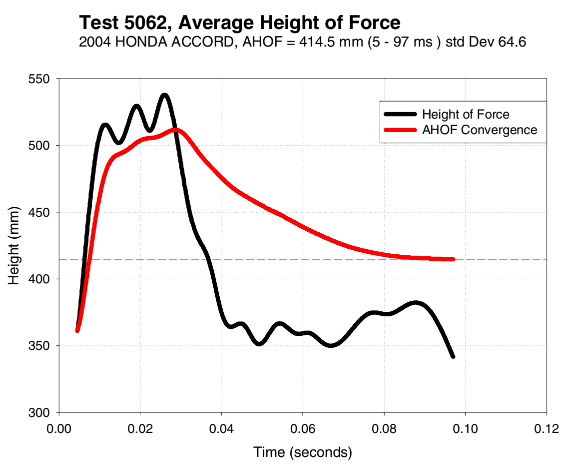

Figure 7. HOF(t) and its convergence for the Honda Accord

The change in HOF(t) for the Accord test can also be observed by examining the forces on the individual rows of the barrier, shown in Figure 8. The barrier rows are numbered from the bottom and increase upwards. Thus the row 1 curve is the lowest row from 125 to 250 mm above the ground. Evaluation of the test film indicates that the secondary impact measured by rows 1 to 5 resulted from the engine striking the load cell barrier.

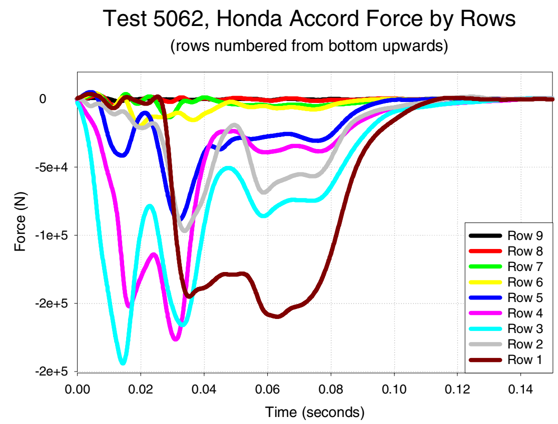

Figure 8. Row forces for the Honda Accord test

By comparison the HOF(t) plot for the Dodge Ram converges quickly to its final value as shown in Figure 9. The HOF(t) does not vary significantly until near the end of the crash.

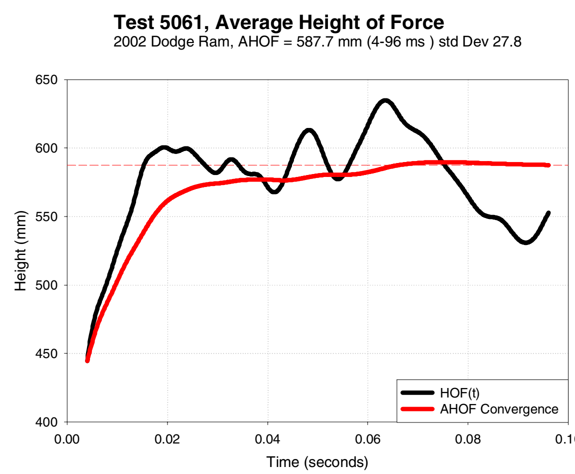

Figure 9. HOF(t) and its convergence for the Dodge Ram

The Dodge Ram measured most of its force in Rows 3 and 4 with smaller contributions from rows 5 and 8 as shown in Figure 10. The relative magnitudes of the row forces remained constant contributing to the stable HOF(t). Row 8, shown in blue, measured 13 percent of the peak row force. Row 8 is almost completely above the standard NCAP barrier and this force is data that would not have been measured in an NCAP test, but would have been transmitted to the plate above the NCAP barrier. Rows 8 and 9 had a peak force that was about 5 percent of the peak

total force for the SUV and pickup tests. These high impact forces certainly contributed to the increased AHOF measured in all of the high resolution barrier tests.

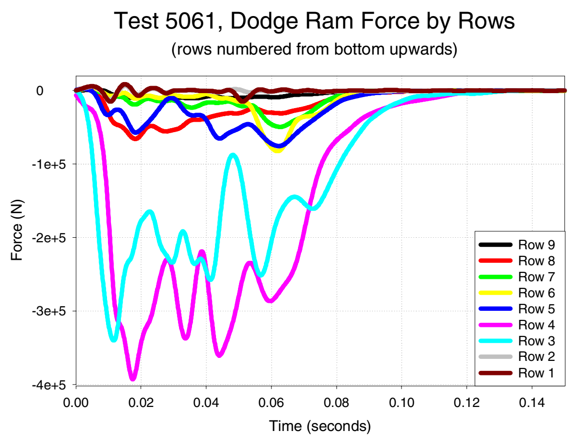

Figure 10. Row forces for the Dodge Ram test

Initial Stiffness

The initial stiffness metric was developed to characterize the initial slope of the force deflection profiles measured in rigid barrier testing. This is of interest because examination of the force-deflection profiles measured in NCAP frontal barrier tests indicated a consistent variation in the initial slope between cars and LTVs. Force deflection profiles were computed for each NCAP test. The profiles were then averaged by vehicle categories using the vehicle test weight. The average profiles are shown in Figure 11. The legend lists the vehicle categories and the number of NCAP tests that were averaged to compute the force deflection profile.

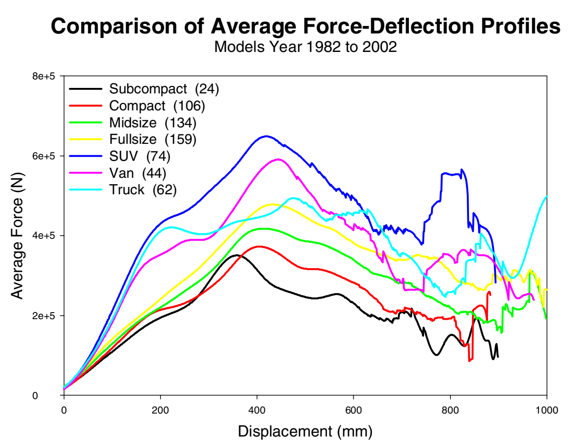

Figure 11. Average force-deflection profiles from NCAP test data

From 0 to about 200 mm of deflection, the average slope for SUVs, pickups and minivans were very similar and much higher than the corresponding slope for the passenger cars. The initial stiffness measure was developed to provide a numerical measure of this difference between passenger vehicles and LTVs. It was hypothesized that the initial rise in force could lead to increased door intrusion velocity in a side struck vehicle. Several methodologies were evaluated to systematically estimate the early slope in the force deflection profile [3]. The resulting initial stiffness was estimated by computing a linear fit that was constrained to start within the first 200 mm of the force defletion profile. The linear fit must have an R^2 value > 0.95. The slope of the longest straight line, greater than 75 mm in length was selected as the initial slope for the force deflection curve. The initial stiffness was computed for each of the NCAP tests and is plotted in Figure 12 below.

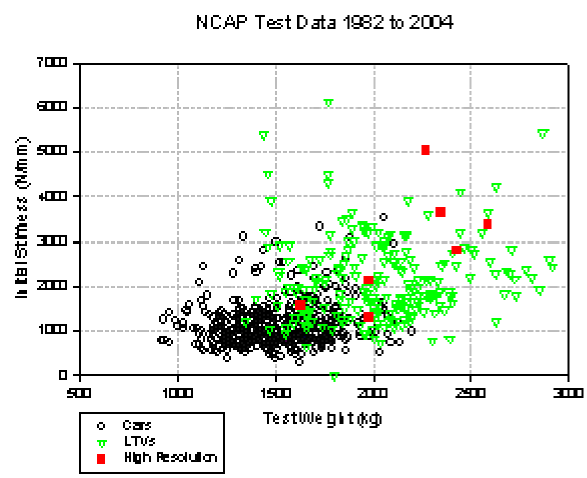

Figure 12. Initial stiffness measures for barrier tests

The initial stiffness measures for this test series are shown in Table 4 along with the earlier results from the NCAP testing program. Similar to the AHOF measures, almost all of the stiffness measures increased in the HR test program. The HR Explorer had a dramatic increase in stiffness compared to the NCAP test. Table 4 shows the percent change relative to the HR stiffness measures.

Table 4. Initial Stiffness measures

	NCAP Stiffness	HR Stiffness (N/mm)	Change
Honda Accord	1467.6	1593.1	7.9 %
Chevrolet Venture	1852.7	2146.4	13.7 %
Dodge Caravan	1347.0	1333.4	-1.0 %
Ford Explorer	2722.0	5002.8	45.6 %

Chevrolet Trailblazer	2478.8	3663.6	32.3 %
Toyota Tundra	1641.5	2829.3	41.2 %
Dodge Ram	2731.5	3401.0	19.7%

Figure 13 shows the significance of the increased initial force for the Ford Explorer. The initial stiffness regressions are shown as dashed lines over the force deflection profiles. The length of the lines indicates the longest applicable region with an $R^2 >$ 0.95. The high-resolution test has considerable more energy or area under force-deflection profile.

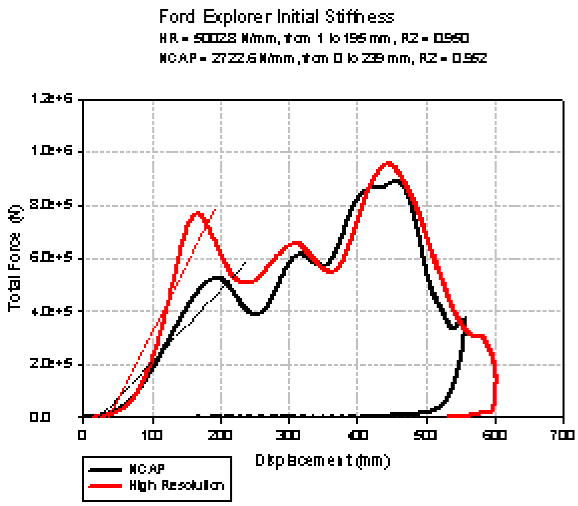

Figure 13. Initial stiffnes for the Ford Explorer

The initial stiffness for the Toyota Tundra tests demonstrated one of the shortcomings of using regression estimates, as shown in Figure 14. In the NCAP test, the inflection between the first two peaks of the force-deflection profile was small enough where it was possible to fit a straight line across the two peaks, resulting in a lower stiffness estimate. The high-resolution test had a more pronounced, or curved, inflection point which prevented a linear regression from spanning the two peaks.

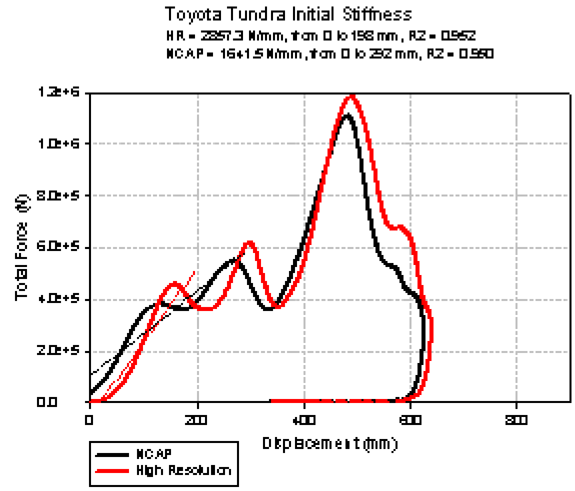

Figure 14. Initial stiffness for the Toyota Tundra

Overall, these test results raise some concern about the calculation of the initial stiffness measure from the NCAP test data. All but one of the vehicles had higher initial stiffness measures in the high-resolution test series. If this trend is consistent, then fleet correlation studies will have been conducted using underestimated stiffness values for the striking SUVs and pickups.

Injury Measures

The injury measures for the 50th percentile male drivers are shown below in Table 5. The injury measures are generally low with the exception of the Venture HIC15. This occurs between 69 and 84 ms when the driver's head appears to bottom out the air bag.

Table 5. Driver injury measures

Model	15 ms HIC	Max Nij	3 ms Clip	Chest Def	Left Femur	Right Femur
ACCORD	310.7	0.21	41.0	33.4	319	727
VENTURE	731.0	0.44	39.1	28.8	5366	8720
CARAVAN	553.4	0.53	51.7	40.4	6285	7336
EXPLORER	427.8	0.52	54.4	33.3	6486	6077
TRAILBLAZER	443.7	0.55	57.5	37.9	6111	6157
TUNDRA	352.9	0.36	47.9	31.4	3722	3475
RAM	381.8	0.30	48.0	33.6	2366	3508

The corresponding injury measures for the belted 5th percentile passenger are shown in Table 6. There were three injury criteria exceeding the reference values, the Caravan left femur compression, the Trailblazer 3 ms chest acceleration, and the Ram Nij in tension-extension (between 60 and 80 ms). The neck extension moment for the Ram passenger

exceeded 28 N-m between 50 and 80 ms. The Trailblazer 3ms Clip occurred between 63 and 66 ms and had a peak Neck extension moment of 38 N-m at 55 ms.

Table 6. Passenger injury measures

Model	15 ms HIC	Max Nij	3 ms Clip	Chest Def	Left Femur	Right Femur
ACCORD	237.0	0.41	42.4	29.6	888	293
VENTURE	243.6	0.44	46.4	25.4	3275	2881
CARAVAN	586.8	0.35	50.4	14.4	6897	3724
EXPLORER	259.2	0.43	53.6	27.9	2194	1361
TRAILBLAZER	568.3	0.98	66.8	36.1	4798	3026
TUNDRA	695.8	0.47	59.3	29.9	3630	858
RAM	275.6	1.17	50.3	37.4	4878	1199

Intrusion Measurements

The intrusion measurements for the seven vehicles are plotted in Figure 15. The Venture generally had the largest intrusions with the two instrument panel intrusions in the IIHS marginal region. The brake pedal for the Caravan and Trailblazer were in the IIHS good region, along with both Instrument panel measurements for the Explorer.

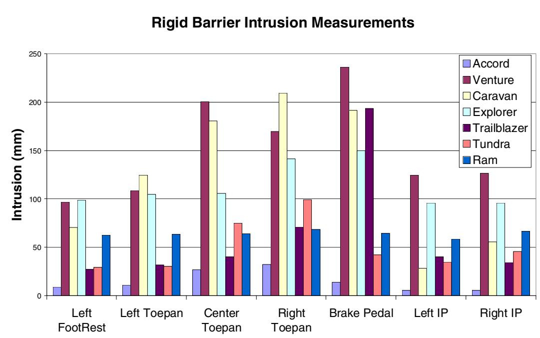

Figure 15. Intrusion measurements for high resolution barrier tests

Rigid Barrier Conclusions

The high-resolution load cell barrier appears to have operated properly and provided good data for the seven tests in this series. The peak forces were less than 2/3 of the rated load cell capacity. The 125 mm load cell has provided improved resolution. This series did bring into question the compatibility measures derived from previous NCAP test data. Significant load was measured above the standard load cell barrier. As a result, neither the AHOF nor the initial stiffness measures demonstrated test-to-test consistency. Repeat tests using the 125 mm barrier will be necessary to evaluate repeatability of these peformance measures. The test vehicles were selected to have a distribution of performance metrics. The HR barrier tests indicated that the performance metrics for the vehicle pairs were not as different as expected from NCAP test results. Figure 16 shows the AHOF and initial stiffness from the NCAP and HR barrier tests. For all three vehicle pairs the difference in AHOF for the HR tests is reduced as shown by the AHOF difference between the pairs of outlined and filled markers in Figure 16.

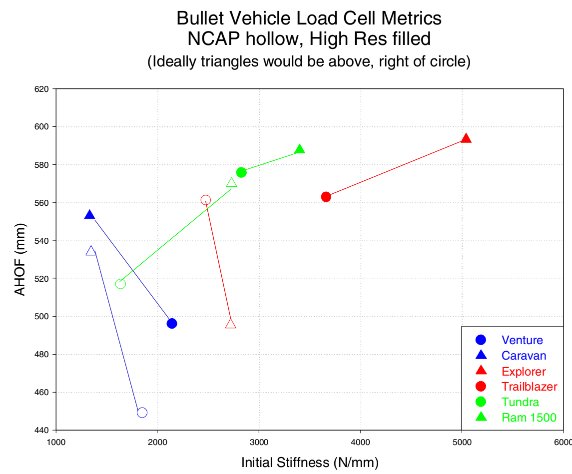

Figure 16. Distribution of compatibility measures for vehicle pairs

FULL FRONTAL VEHICLE TO VEHICLE

Six full frontal vehicle-to-vehicle tests were conducted. Each test was run against a stationary 2004 Honda Accord. The impact speed was established to obtain a 56 kph change in velocity for the struck Honda Accord. The test matrix is shown in Table 7 below. The Honda Accord contained a 50th percentile Hybrid III driver with Thor-Lx legs. The target vehicle also contained a 5th percentile female Hybrid III right front passenger.

Table 7. Full Frontal Bullet Vehicles

Test	Year	Make	Model	Weight Ratio	Speed (kph)
5109	2001	CHEVROLET	VENTURE	1.20	102.0
5112	1999	DODGE	CARAVAN	1.22	101.2
5081	2002	FORD	EXPLORER	1.41	95.6
5113	2002	CHEVROLET	TRAILBLAZER	1.46	94.5
5085	2002	TOYOTA	TUNDRA	1.48	93.8
5041 5247	2002	DODGE	RAM 1500	1.56	92.5

There was moderate override early in the tests with the SUV and pickup vehicles as shown in Figure 17. Overall, the crash interaction was very good with no signs of significant occupant compartment intrusion and good structural interaction between the target and the bullet vehicles.

Figure 17. Full frontal Tundra into Accord test

The normalized driver injury measures are shown in Table 8. below. In two of the tests, number 5112 and 5041, the driver air bag ripped during deployment. Honda repeated the test for the Ram and those results are shown in Table 8. No driver injury measures are available for the Caravan test.

Table 8. Injury measures for Honda Accord drivers in full frontal tests

Test	Striking Vehicle	15 ms HIC	Max Nij	3 ms Clip	Chest Deflection	Left Femur	Right Femur
5062	Rigid Barrier	310.7	0.21	41.0	33.4	319	727
5109	Venture	169.7	0.24	36.0	32.8	1231	2038
5081	Explorer	508.8	0.31	43.9	29.4	3280	5110
5113	Trailblazer	273.0	0.27	35.4	27.6	1896	2269
5085	Tundra	805.1	0.31	46.5	29.9	1249	5218
5247	Ram 1500	212.1	0.42	40.4	29.7	3589	2875

The test with the Tundra has a high HIC15 between 85.8 and 100.8 ms when the dummy's head appears to bottom out the air bag and hit the steering wheel. The driver struck by the Explorer had higher injury criteria for all injury measures than the driver struck by the lower, softer Trailblazer. There was no similar trend for the pickups.

Figure 18 plots the normalized injury measures for the Accord drivers struck by vehicles with the higher AHOF / Stiffness against the same criteria for the lower measures of each pair. The Explorer had higher AHOF and stiffness and generated higher Honda driver injury criteria than the Trailblazer. The Ram had a higher AHOF and stiffness, yet generated lower Honda driver injury criteria compared to the Tundra. The two vehicle pairs provide opposite conclusions in this test series.

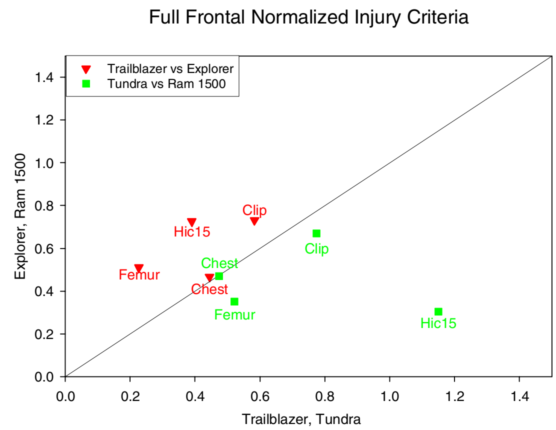

Figure 18. Normalized injury for vehicle pairs

The safety systems performed well for all of the Honda Accord passengers. The injury measures are generally low as shown in Table 9. For the two Ram tests, the Honda passenger injury measures repeated remarkably well. There are no observed trends between the passenger injury measures and the striking vehicle characteristics.

Table 9. Injury measures for Honda Accord right front passengers in full frontal tests

Test	Striking Vehicle	15 ms HIC	Max Nij	3 ms Clip	Chest Def	Left Femur	Right Femur
5062	Rigid Barrier	237.0	0.271	42.4	29.6	888	174
5109	Venture	242.6	0.264	44.8	16.4	2166	2291
5112	Caravan	224.9	0.332	42.3	18.2	2884	2337
5081	Explorer	282.2	0.283	47.3	15.7	3619	3503
5113	Trailblazer	155.3	0.383	35.2	16.3	3483	3716
5085	Tundra	218.4	0.502	45.5	16.5	3680	2882
5041	Ram 1500	255.2	0.321	43.9	14.9	3391	3232
5247	Ram 1500	286.7	0.297	48.1	17.0	3891	2259

Intrusion Measurements

The intrusion measurements for the struck Honda Accords are shown in Figure 19. The SUV and pickup striking vehicles produced considerably more intrusion than the two minivans. Only the Accord struck by the Ram exceeds the IIHS limits for good

performance at the right toe pan and brake pedal locations.

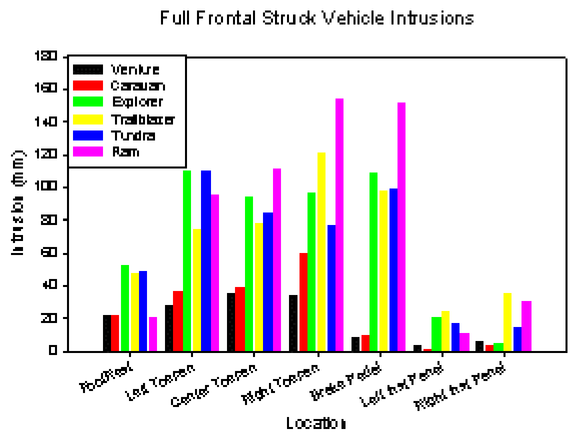

Figure 19. Full Frontal Intrusion measurements

The low intrusions for the minivan tests can be understood by examining the intrusion measurements for the striking vehicles, shown in Figure 20. Here the minivans clearly stand out as having significantly more intrusion than the SUVs and pickups. The Venture had brake pedal and instrument panel intrusions that exceeded the the IIHS good region. The striking and struck vehicle intrusions for the minivans tests are completely opposite of those measured in the SUV and pickup tests.

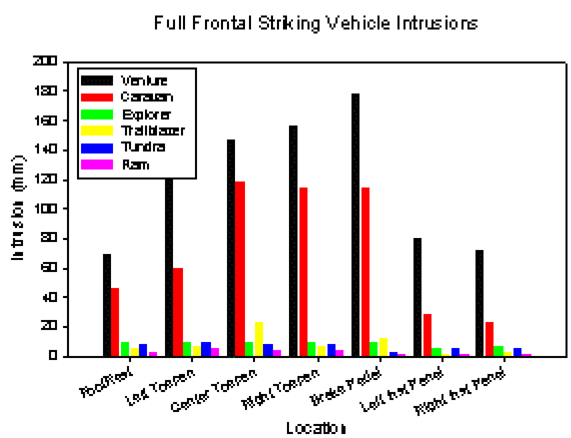

Figure 20. Full frontal striking vehicle intrusion

Comparison of Crash Pulses

Figure 21 plots the acceleration measured near the Honda Accord driver seat for all six of the full frontal tests. The acceleration for the rigid barrier test is also shown as the dark green line. The full frontal tests are suprisingly similar to the rigid barrier test. The vehicle-to-vehicle accelerations appear to have a slightly shorter duration. This is consistent with the passenger injury measures which were fairly consistent for all tests. Only the femur force measurements were consistently higher for the driver and passenger dummies.

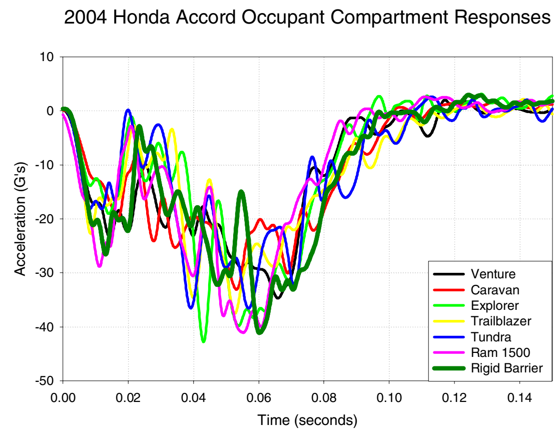

Figure 21. Comparison of Honda Accord acceleration measurements

FRONTAL 50% OFFSET TEST SERIES

An identical series of bullet vehicles were run into a stationary Honda Accord using the same impact speeds as the full frontal test series. In this test series, the vehicles were aligned so that the bullet vehicle would engage 50 percent of the width of the Honda Accord. The collinear offset test matrix is shown in Table 10.

Table 10. Offset Test Matrix

Test	Year	Make	Model	Test Weight	Speed (kph)
5110	2001	CHEVROLET	VENTURE	1943	102.8
5116	1999	DODGE	CARAVAN	2015	100.9
5080	2002	FORD	EXPLORER	2292	94.6
5040	2002	CHEVROLET	TRAILBLAZER	2371	93.0
5086	2002	TOYOTA	TUNDRA	2431	93.8
5111	2002	DODGE	RAM1500	2527	92.9

There were no test anomalies in the offset test series. The injury criteria for the Honda Accord drivers in the Honda Accord were all generally low and are shown in Table 11. For comparison the injury measures from an IIHS 64 kph offset deformable barrier test are included.

Table 11. Injury measure for Honda Accord drivers in offset frontal tests

Test	Striking Vehicle	15 ms HIC	Max Nij	3 ms Clip	Chest Def	Left Femur	Right Femur
4450	IIHS ODB	290.8	0.329	40.7	31.3	444	645
5110	Venture	273.4	0.215	37.9	28.1	1207	1965
5116	Caravan	387.6	0.302	38.6	26.4	1916	2243
5080	Explorer	264.9	0.330	40.5	33.4	3787	3967
5040	Trailblazer	282.1	0.347	46.2	28.7	3338	4325
5086	Tundra	240.2	0.237	35.2	26.3	3262	3117
5111	Ram 1500	184.9	0.234	33.7	26.4	2763	2418

The struck driver injury measures do not show a consistent trend between the striking vehicle characteristics. Figure 22 plots the normalized injury measures for the vehicle pairs. The injury measures generally fall along the 45 degree line indicating similar outcomes for the Accord drivers struck by the higher/stiffer and lower/softer vehicles.

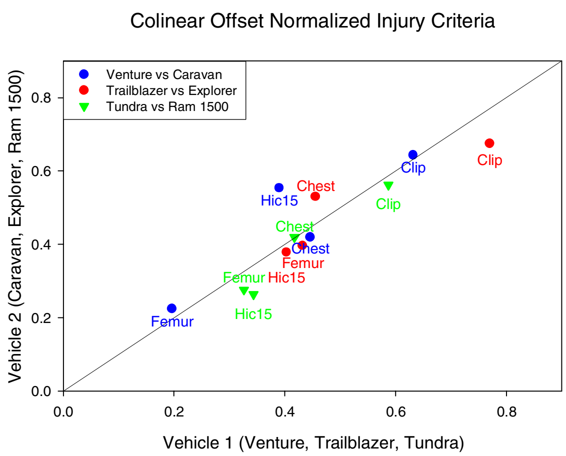

Figure 22. Normalized injury measures for the offset vehicle pairs

The Honda Accord 5th percentile female passenger dummies all had low injury measures and are not shown. The only significant injury measures recorded in this test series were for the drivers of the striking minivans. Both of the minivan drivers had HIC15 values above 90 percent of the accepted reference value.

Intrusion Measurements

Figure 23 shows the intrusion measures for the Honda Accord vehicles that were struck by the various bullet vehicles. The Accord struck by the Explorer had both instrument panel intrusions in the IIHS poor range. The Accord struck by theTundra had left and right toepan intrusions in the IIHS poor range. Only the Accord struck by the Venture had intrusion measurements completely in the IIHS good range.

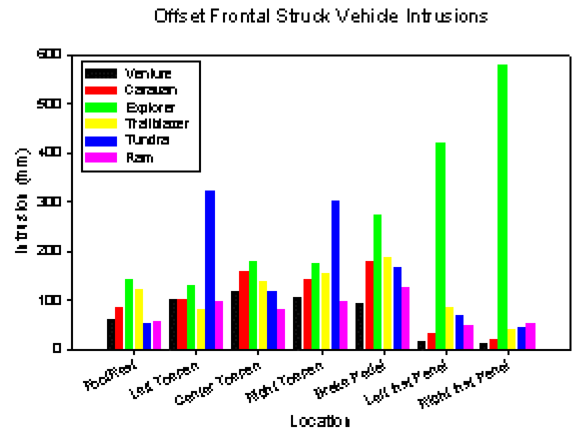

Figure 23. Honda Accord intrusion measurements

The low intrusions measured in the Accords struck by the minivans can again be understood by examining the striking vehicle intrusions shown in Figure 24. Here the Venture has several intrusion measurements in the IIHS unacceptable range. The intrusion measurements for the Caravan are in the IIHS acceptable range. All of the SUVs and pickups have minimal intrusion and are in the IIHS good range.

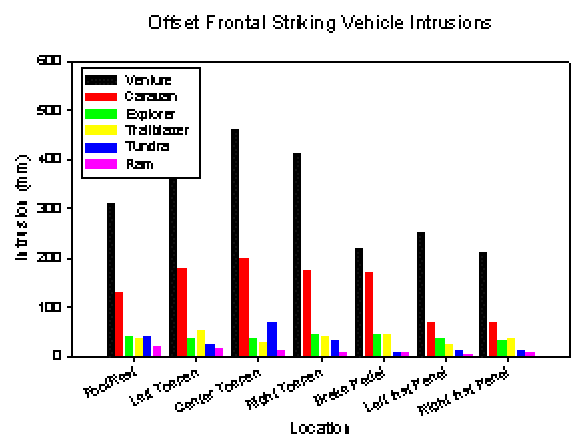

Figure 24. Striking vehicle intrusions

SIDE IMPACT TEST SERIES

The final test series in the program used the same bullet vehicles in FMVSS No. 214 configuration side impact tests. The Honda Accords were struck in the driver’s side. An ES2re driver dummy was used. A SID-2S FRG dummy was seated in the left rear seating position. All tests were run at the same

nominal impact speed, 54 kph, regardless of the mass of the striking vehicle.

Figure 25. Tundra into Accord side impact test

The injury measures for the struck drivers of the Honda Accords are shown in Table 12 below. This table also includes the injury measures from a FMVSS No. 214 configuration test conducted using a ES2re driver dummy in a Honda Accord. Almost all of the peak rib deflections exceeded the threshold value despite the presence of a thorax side air bag. The peak deflection was measured on the lower thoracic rib for all tests including the FMVSS No. 214 test. This lower thoracic rib appeared to be adjacent to the arm rest on the door. The HIC36 measurements were all remarkably low, especially considering the proximity of the dummys head to the hood of the striking vehicles, as shown in Figure 25. The low HIC measures appear to demonstrate the protective performance of the Accord side curtain air bag. The peak abdominal forces generally increase with the mass of the striking vehicle. The injury measures generated by the SUVs and pickups all exceed those in the FMVSS No. 214 configuration. Only the rib deflection measurements would have affected the overall test performance.

Table 12. Side impact Honda Accord driver injury measures

Test	Striking Vehicle	HIC 36	Rib Def	Lower Spine	Abdom. Force	Pubic Force
4862	**214 MDB**	223.4	22.7	50.3	809.7	2405
5146	Venture	128.1	45.5	48.0	597.0	3361
5142	Caravan	68.5	37.0	36.0	622.8	2063
5151	Explorer	249.5	43.5	52.2	987.1	3804
5156	Trailblazer	281.0	45.4	60.0	974.8	4986
5141	Tundra	341.2	47.5	51.5	1404.8	3204
5161	Ram 1500	267.0	45.7	54.4	1343.8	3357

Figure 26 plots the normalized injury measures for the higher / stiffer vehicles against the lower / softer vehicle in the same category. The data points largely lie below the 45 degree line indicating that the crash outcome was worse for the vehicle struck by the lower / softer bullet vehicle. This is in direct opposition with NHTSA's previous fleet correlation [2]. However, the fleet correlation was based on fleet crash data almost completely without side curtain air bags. It appears that head protection provided by side curtain air bags may be a good countermeasure for the head injuries resulting from crashes similar to these.

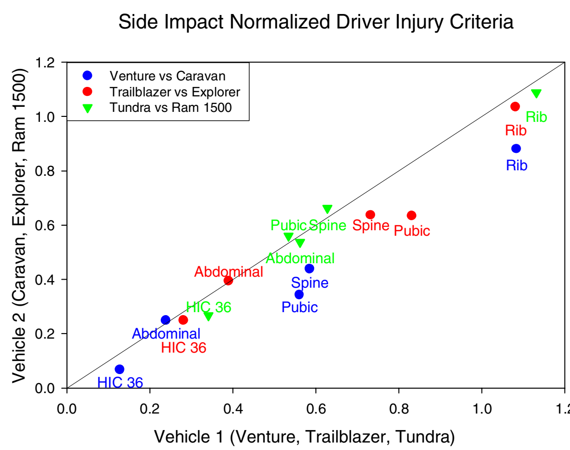

Figure 26. Normalized injury measures for the side impact vehicle pairs

The rear passenger injury measures were generally low as shown in Table 13. This table includes the injury measures from a FMVSS No. 214 configuration test with a SID2s rear occupant. Only the SID-2S FRG struck by the Tundra exceeded any injury tolerance level. The HIC36 for this test was also very close to the tolerance limit. The minivans generated lower injury measures than in the FMVSS No. 214 configuration test. The SUV and pickup impacts produced increased HIC36 measurements. The lower spine and acetabulum measures bracketed the FMVSS No. 214 configuration results.

Table 13. Honda rear passenger injury measures

Test	Striking Vehicle	HIC 36	Lower Spine	Acetabulum Illiac Force
5044	214 MDB	300.1	52.1	3777.9
5146	Venture	288.6	50.0	3565.6
5142	Caravan	283.5	42.5	2727.6
5151	Explorer	568.2	64.2	4038.2
5156	Trailblazer	452.4	63.2	4063.8

5141	Tundra	967.6	114.8	2901.3
5161	Ram 1500	598.7	50.6	3444.3

DISCUSSION

This test program was established to investigate the statistical correlation between vehicle performance measures and struck driver fatality. For all twelve of the frontal tests, only one of the drivers demonstrated a significant risk for serious injury. This driver was struck by the pickup vehicle with the lower performance measures. For the side impact tests, all but one of the struck drivers had a significant risk for serious injury. The one driver with the lower risk of thoracic injury, was struck by the minivan with the higher AHOF and lower stiffness. Neither of these observations support a correlation with the real world crash statistics. There are several factors confounding the conclusions of this test series. Kahane's analysis used data for model year 1991 through 1999 vehicles, this test series evaluated newer vehicles and the results may reflect the improved safety performance. The recent analysis by Austin [13] utilized different data sources and some newer vehicles, yet still found a correlation between AHOF risk of injury in side impact crashes. This test series along with the fleet analysis emphasize the complexity of predicting how vehicle designs will interact with other vehicles, their restraint systems, and the safety outcome for passengers of current and future vehicles.

This high resolution barrier test series unexpectedly brought into question the completeness of the load cell measurements collected using NHTSA's existing load cell barriers, particularly for the larger vehicles in this series. There was a substantial force measured above the older 4 by 9 load cell barriers. Almost all of the compatibility performance measures increased when the vehicles were tested on the taller high resolution barrier. The NHTSA load cell barriers were designed and built twenty years ago with smaller vehicles in mind. There is a need to update the crash walls used in NHTSA testing. Because the bullet vehicles were selected using incorrect compatibility metrics, the difference in the AHOF and stiffness measures were not as significant as originally intended.

NHTSA has already initiated repeatability testing to evaluate the 125 mm load cell barrier measurements. Preliminary test results indicate that the AHOF and stiffness measures can have acceptable repeatibility. However, it is important to measure and correct for any vertical impact misalignment.

The test series also indicated concerns regarding the acceptance criteria used to review the historical NCAP data. Previously, test data were accepted if the force and accelerometer measurements closely correlated each other. The results of the Explorer NCAP test indicate that the acceptance criteria need to impose stricter requirements on the transfer function between the barrier force input and the accelerometer measured response. Research is underway to quantify appropriate acceptance criteria and to reevaluate the historic NCAP data.

The AHOF was developed as a performance measure because it is a simple method to distill the time varying load cell measurements down to a single number that is easily related to the vehicle design. The AHOF generally aligns with the primary energy absorbing structure of the vehicle. Furthermore, large differences in AHOF generally leads to frontal-frontal crash override behavior as shown in Figure 17. However, this test series and others [12] have shown that override does not always relate to a reduced safety outcome for the driver of the vehicle with the lower AHOF. These results seem to show that for lower speed vehicle-to-vehicle crashes, some override can improve occupant safety by providing a slower decceleration; however, at higher impact speeds this can lead to occupant compartment intrusion.

For side impact crashes, the safety correlation with the AHOF difference seems to have been reduced, if not removed, by the presence of side curtain air bags. While not a suprising conclusion, vehicle compatibility is most readily evaluated from real world crash statistics, yet the historical trends may not always apply to future vehicles. For front-to-front crashes manufacturers are introducing secondary energy absorbing structures designed to better interact with passenger cars. It may take several years to aquire enough crash data to see if these vehicle designs perform as intended.

Numerous methods have been used to evaluate vehicle stiffness and its potential contribution to vehicle compatibilty. Stiffness is an intuitively significant measure, that is hard to quantify in a rigorous manner. In a recent NHTSA study [11], the initial stiffness estimate was the only one of several stiffness estimates to show any real world correlation. However, this measure was developed

from evaluation of NCAP barrier data and has not been rigorously linked to real world crash mechanisms. More research is needed to better understand the role of stiffness in vehicle-to-vehicle crashes and to improve the consistency and relevance of these measures.

Crash severity plays a significant role in the evaluation of vehicle compatibility. NHTSA's fleet correlations evaluate the probability of driver fatality, yet these test results generally indicate a low probability of serious injury. It is questionable whether this test series, particularly the offset tests, evaluated the same crash severity that was responsible for the fleet correlations. It is also likely that the safety performance of the target vehicle's restraint systems were improved from the restraint systems that led to previous fleet correlations.

None of the three test series provided significant insight or understanding to explain the fleet correlations with AHOF and stiffness metrics. The bullet vehicles did not have the distribution of AHOF and stiffness measures that was expected when the vehicles pairs were selected. The restraint systems in the target vehicle appear to have performed very well and likely reduced any effects to the varying compatibility of the bullet vehicle pairs. The side curtain air bags appear to have greatly reduced the potential for head injury in the side impact tests. While this test series does not help to explain the observed fleet safety correlations with the proposed compatibility measures, it does provide significant insight into the complex safety interactions and mechanics of vehicle crash compatibility.

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